Cubism - Braque’s Bottle and Fishes, Paris c.1910-12

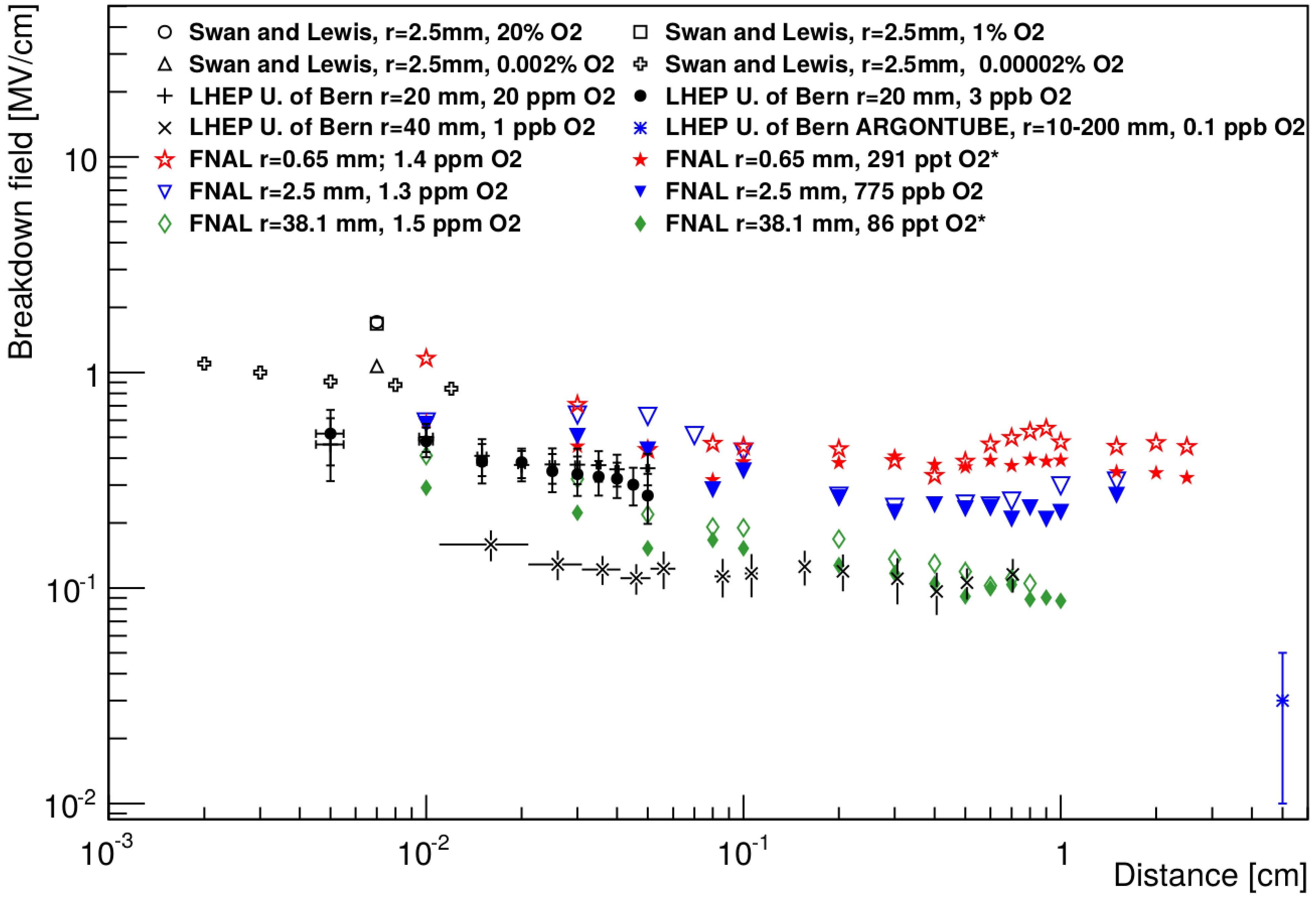
A LArPix detector concept; Advanced Liquid Argon

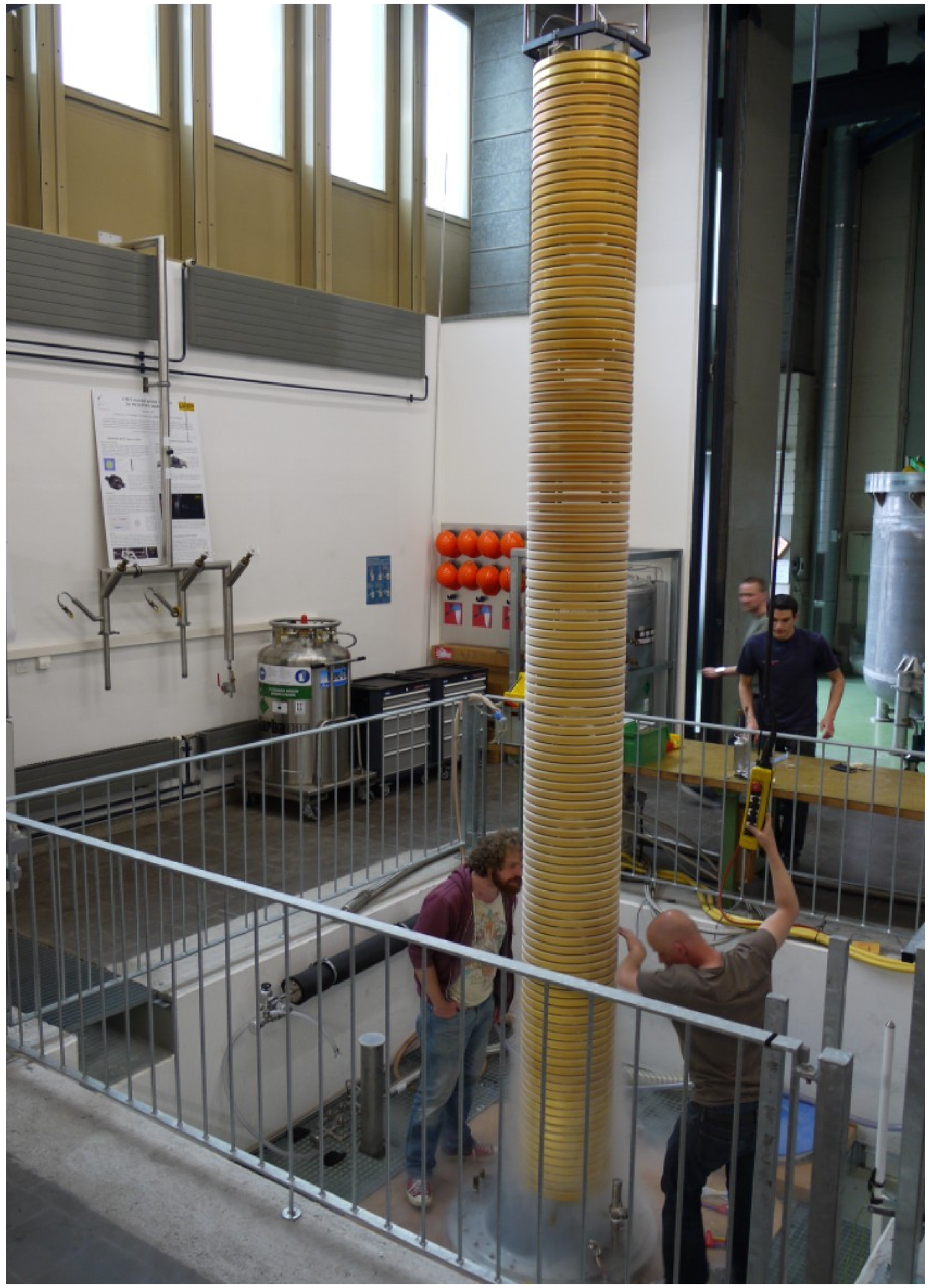
DEEP UNDERGROUND NEUTRINO EXPERIMENT

Module of Opportunity for DUNE
BNL
Nov 13th 2019
James Sinclair, LHEP

Advanced LArTPCs based on extensive R&D

ArgonCube emerged from the ArgonTube studies of long drift length in LAr (5m) and the associated HV.





The focus of ArgonCube is developing LArTPCs for maximal reliability and detector sensitivity.

ArgonCube in the Near Detector Complex

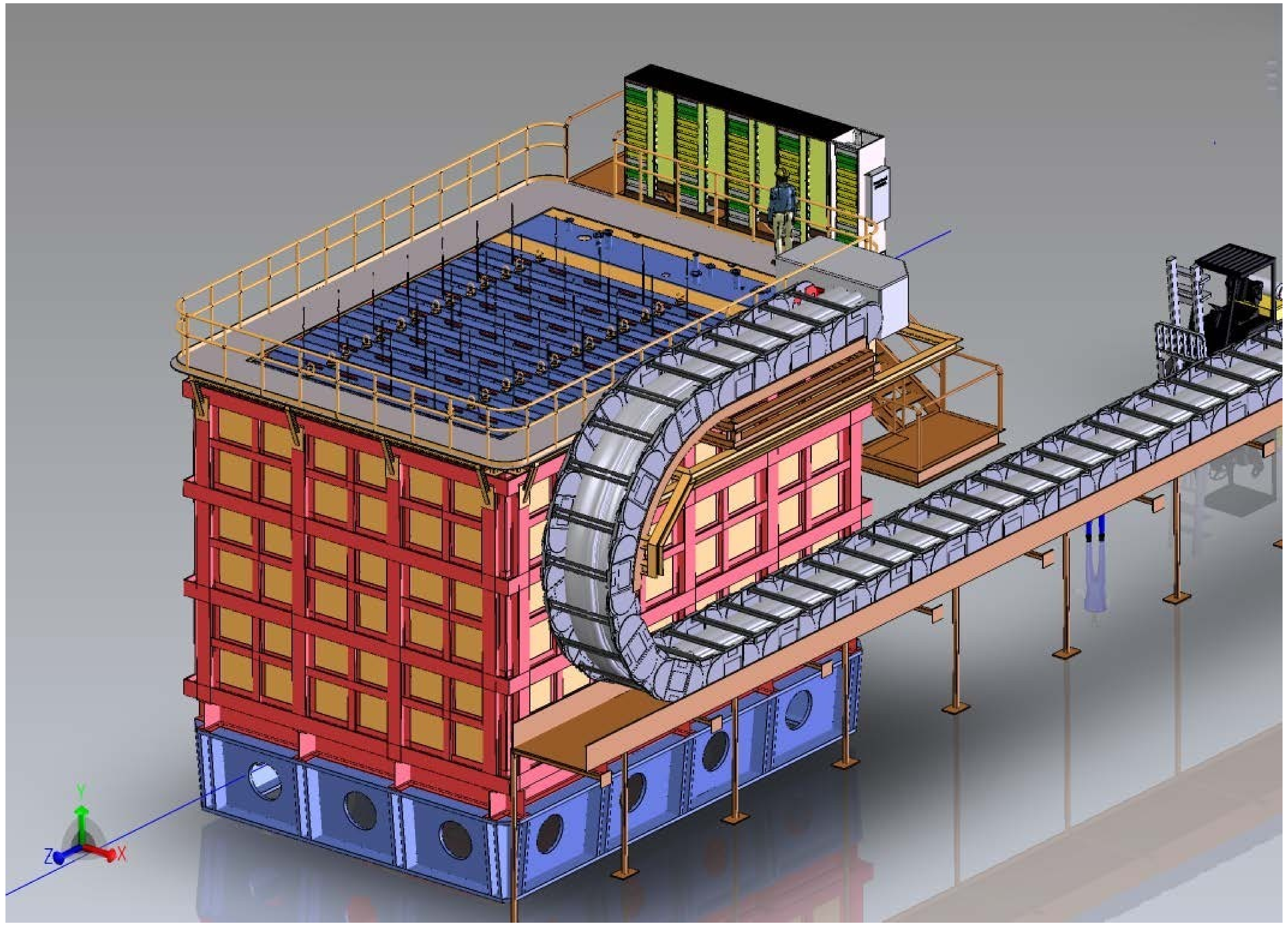
Segmented detector with independent TPC modules sharing a common cryostat

Reduce pile up in a high multiplicity environment, while maximizing active volume.

Short drift distances
- Low cathode voltage
- Reduced stored energy
- Reduce purity requirements
- No clearance volume (G10 structure)

Contained scintillation light

Unambiguous charge readout



35 modules, 70 TPCs. 3 m x **7 m** x **5 m** long.
67 t FV 11 ν/s (0.3 ν/s/module).

Applications to a Far detector

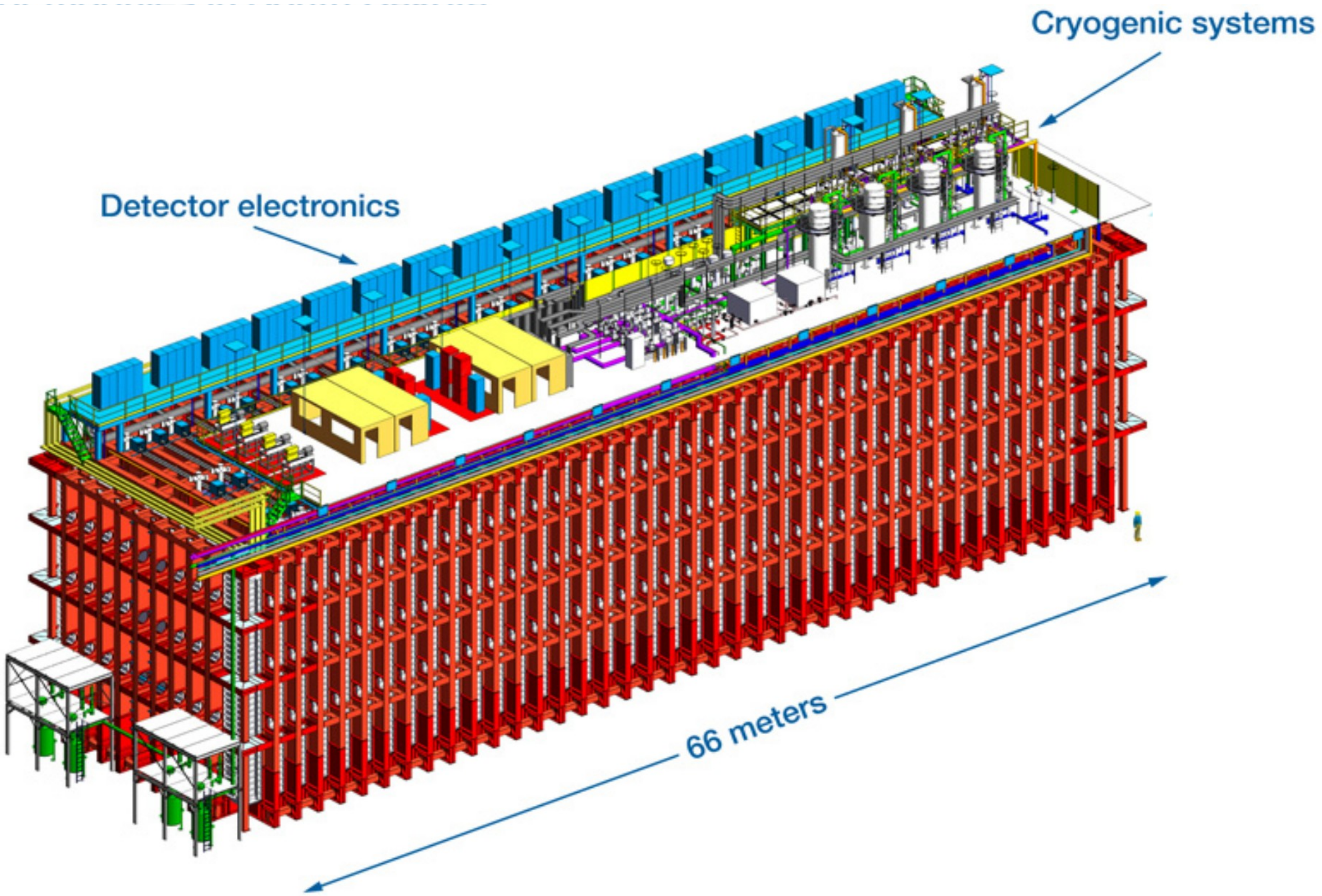
Many of the aspects that made ArgonCube applicable to the ND are beneficial to the FD.

Unambiguous charge readout

Reduced HV risks

Contained scintillation

Increased active mass



Assuming the same cryogenics,
segmenting the detector volume.

Cryostat internal dimensions **62 m x 14 m x 15.1 m (wide), 17 kt.**

LArPix Charge Readout; Intrinsic 3D

See Dan Dwyer’s talk

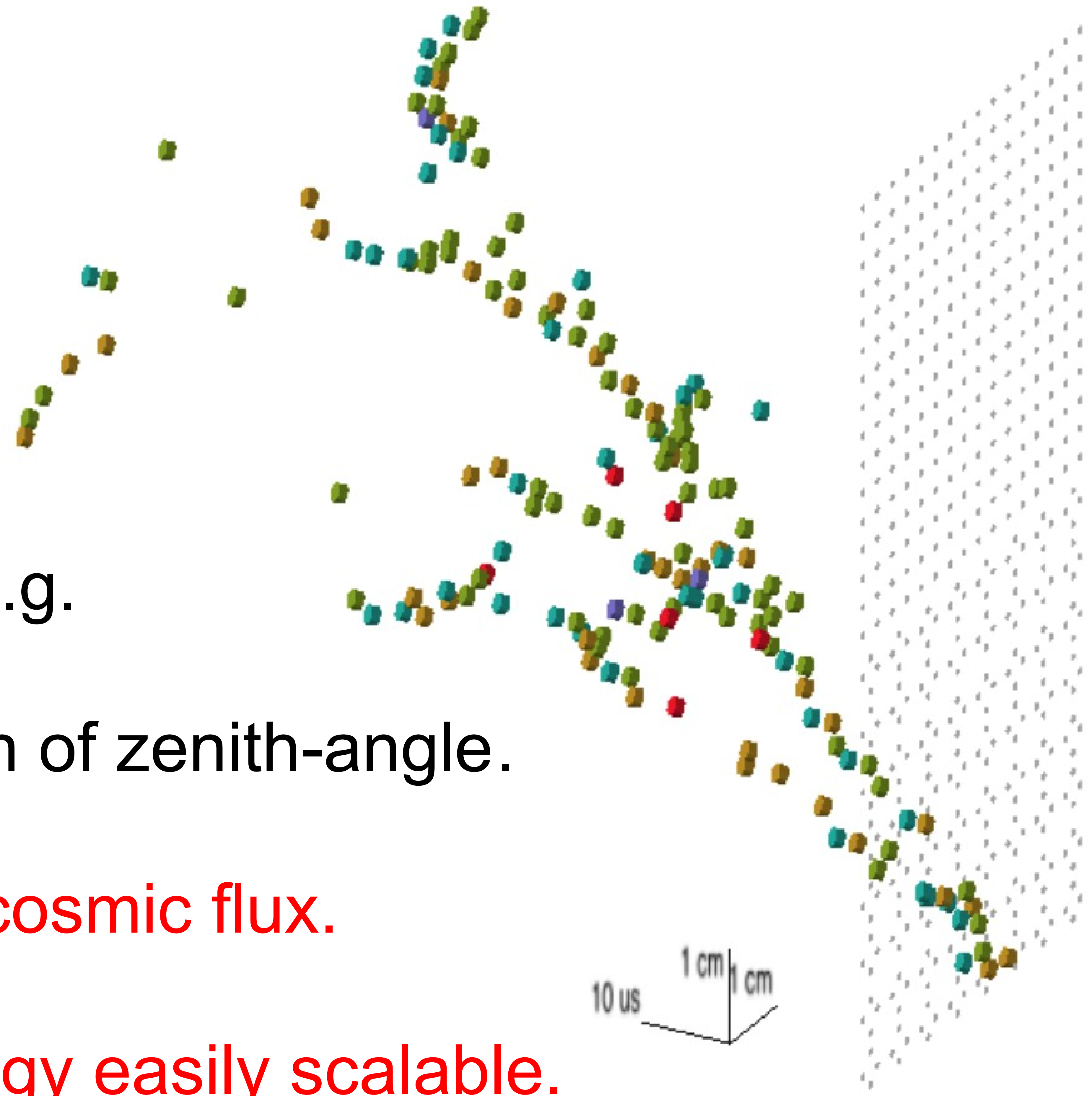
Uniform reconstruction efficiency as a function of particle direction.

long-baseline oscillation programme

Improved the background detection efficiency.
Improved energy estimation of beam neutrinos as high-angle particles not missed.

Other physics searches

Advantageous for events with no preferred direction e.g. proton decay or SN-neutrino.
Uniform reconstruction of solar-neutrinos as a function of zenith-angle.



Low data rate: O (0.5) $\mathrm{Mbs^{-1}m^{-2}}$ for 1 m drift in surface cosmic flux.

Standard PCB production techniques make this technology easily scalable.

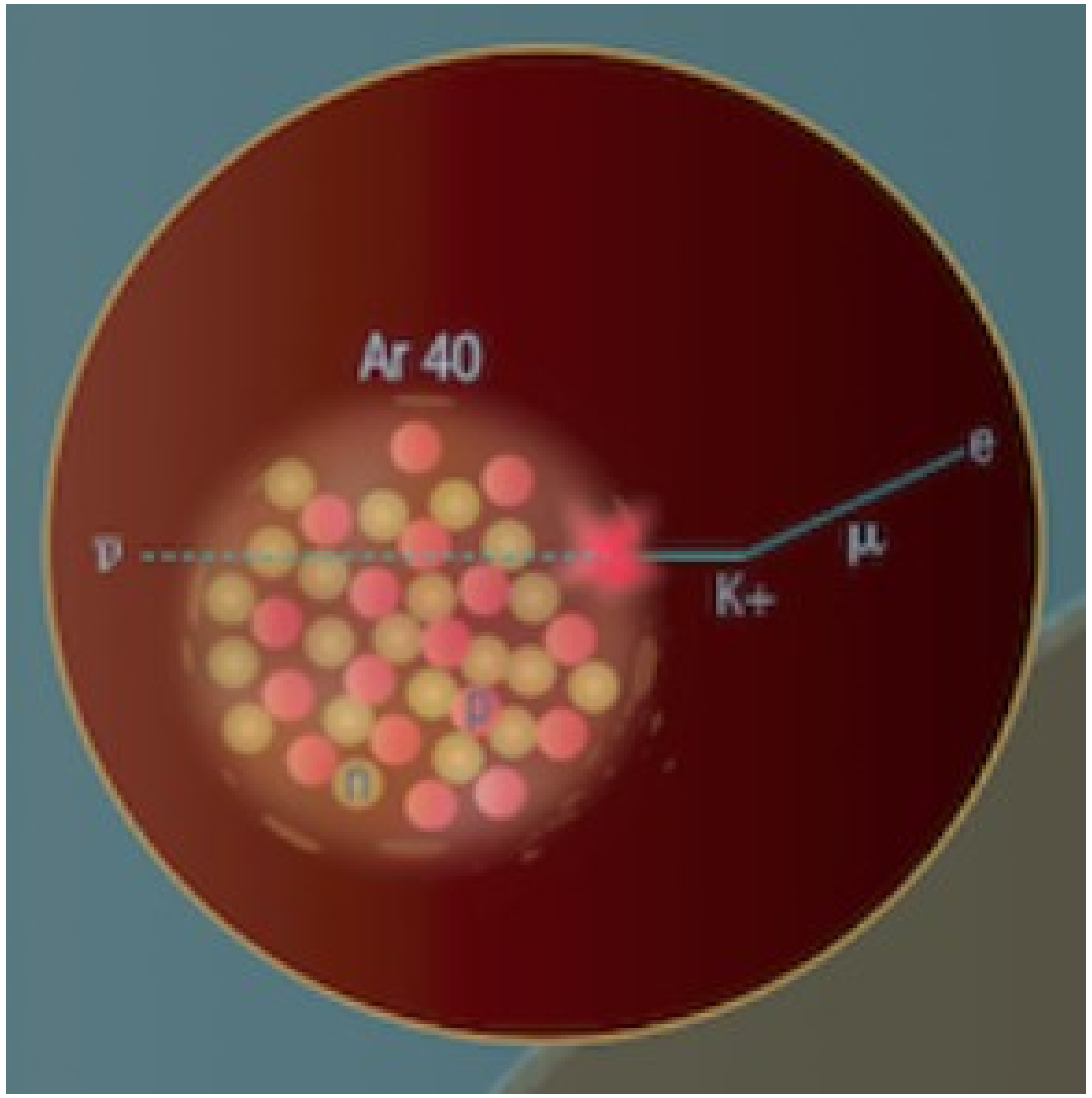
Contained Scintillation light

Provide precise local trigger for low-energy events. Mitigate dead time around high-energy events elsewhere in the detector.

Prevent light from multiple signals piling-up in the same drift window e.g. a large SN-neutrino signal.

Provides complementary calorimetry from the scintillation light, improved PID and BG rejection.

Improved sensitivity for solar- (<10 MeV) and supernova-neutrinos (10 MeV to 30 MeV), as well as the proton-decay channel $p \rightarrow K^+ + \bar{\nu}$, where sensitivity to the 12.4 ns K^+ lifetime is vital.



An ArgonCube FD concept

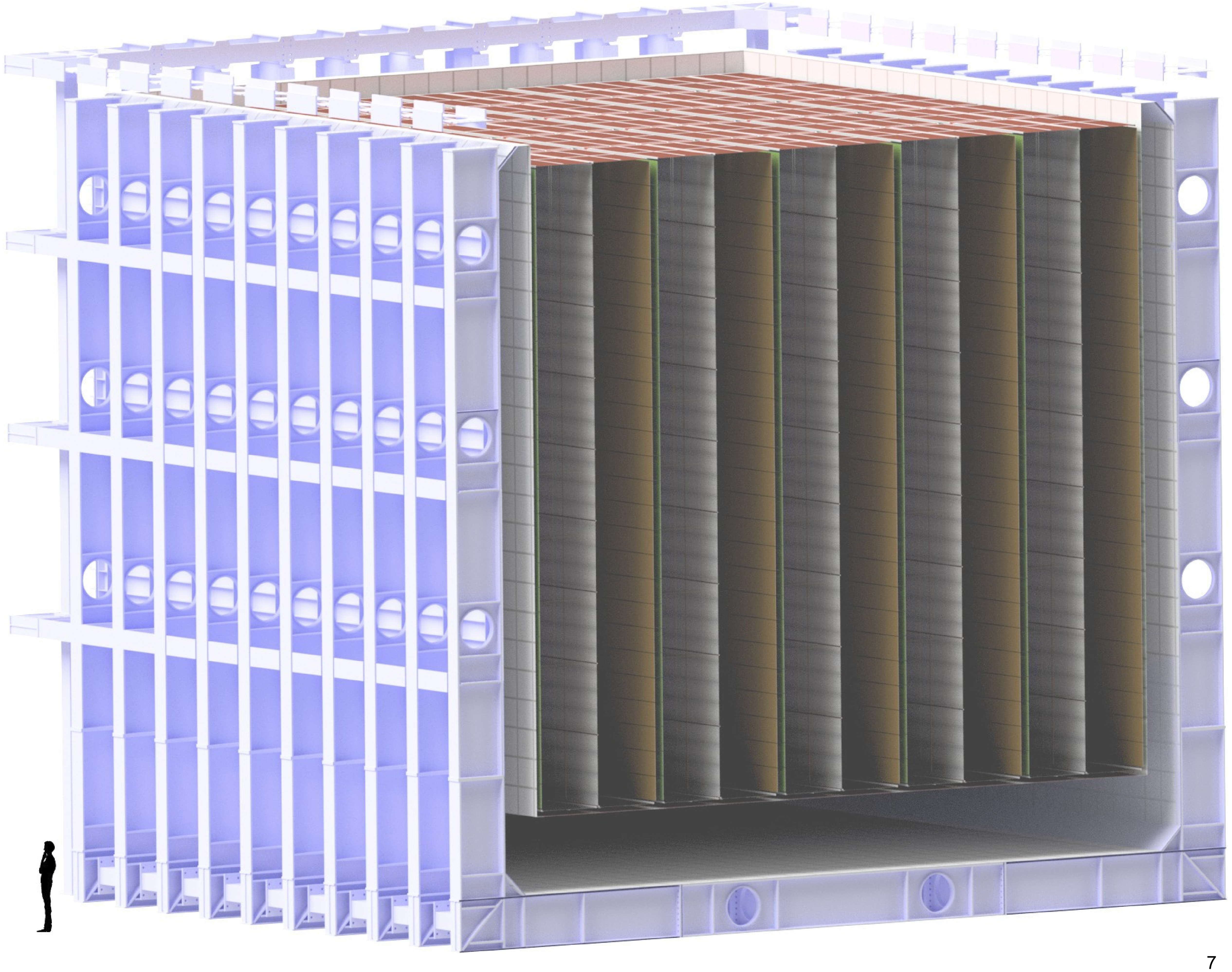
Drift length divided into 10 TPCs
(5 cathodes)

Cathodes divided into 20 sections along the beam.

200 individual TPCs are contained within an opaque G10 structure.

Detector volume 61.8 x 13.6 x 14.9 m^3.

Active volume ~21% larger than DUNE SP

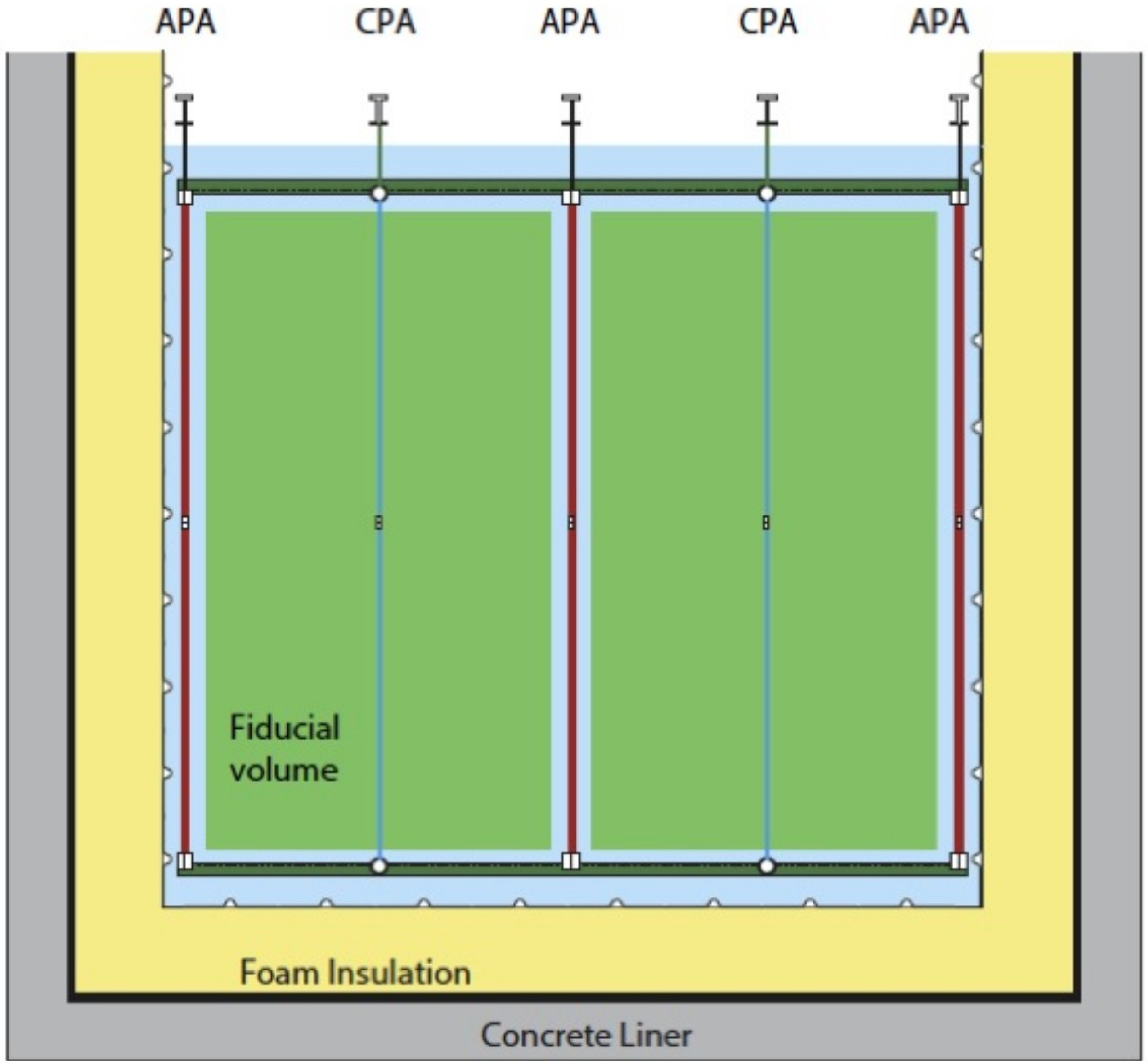


Segmenting the drift; Cathode Voltage

The low data rate and scalability of the LArPix readout reduces the desire to limit the number of anodes.

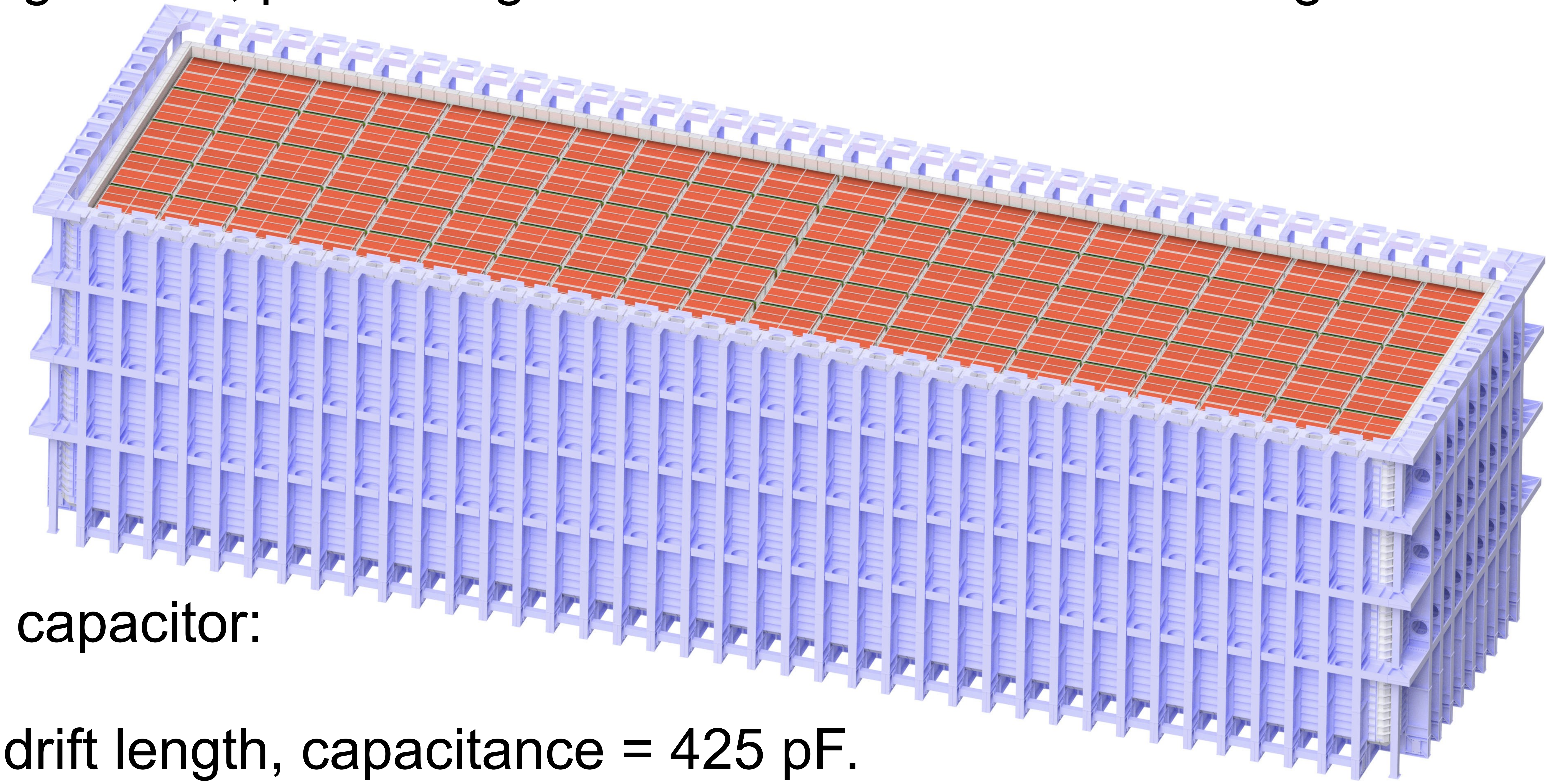
15.1 m drift divided into 10 TPCs, 30 mm thick pixel anode planes, 5 mm cathodes, 21 cm of dead material.

1.47 m drift length, only −73.5 kV required to maintain 500 V cm^{-1}.



Segmenting Cathode; Stored Energy

The length is segmented into 20 independent cathodes. Each 3.09 m cathode section would be electrically isolated from its neighbours, preventing a HV breakdown from affecting the entire detector volume.



Approximating as a parallel-plate capacitor:

Cathode 13.6 x 3.09 m^2, 1.47 m drift length, capacitance = 425 pF.

At −73.5 kV, the combined 850 pF corresponds to a stored energy = **2.2 J/TPC pair**.

Resistive Field Shell TPC

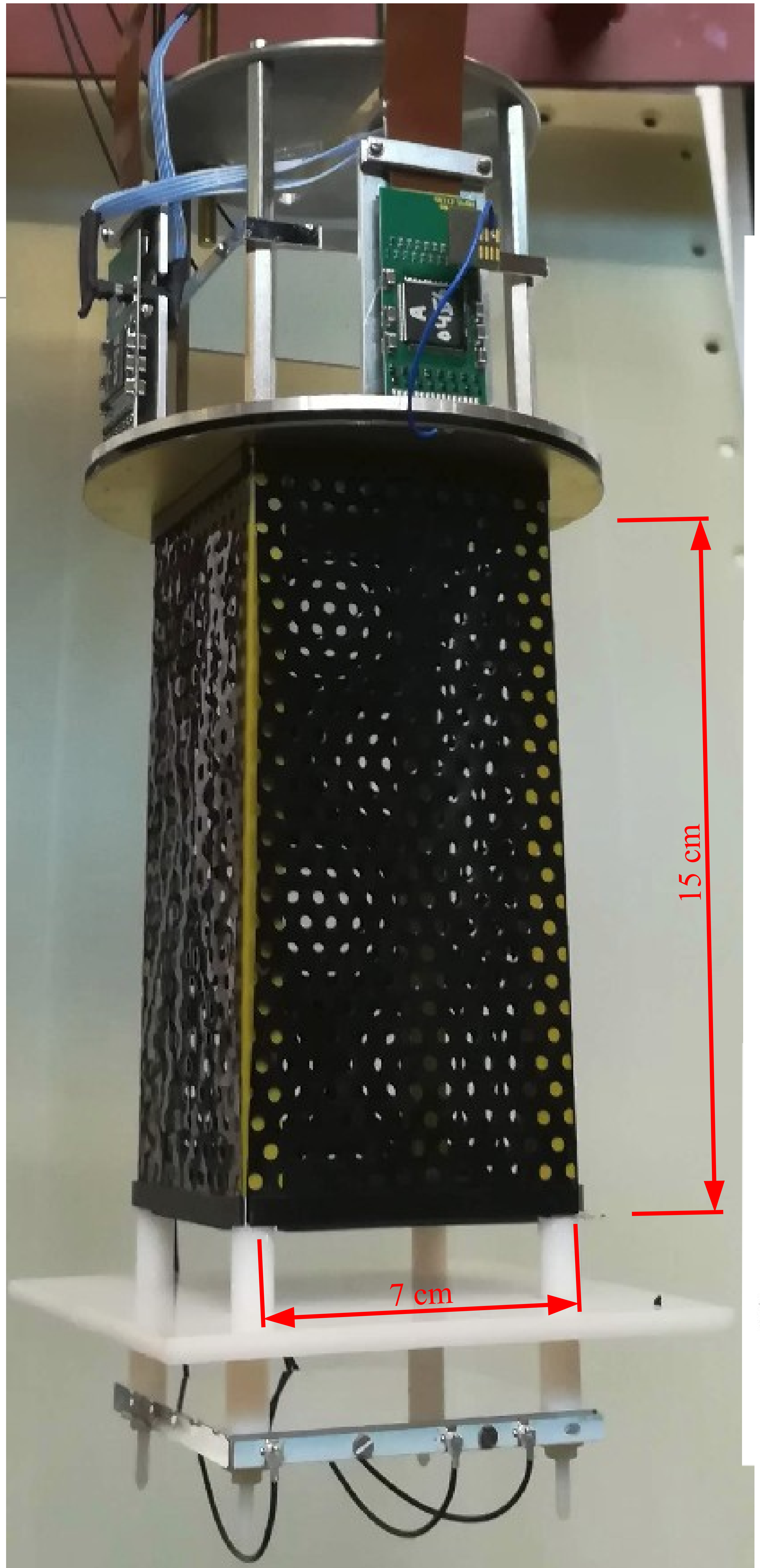
Fitting multiple TPCs inside a kt scale cryostat requires a new approach to E-field shaping.

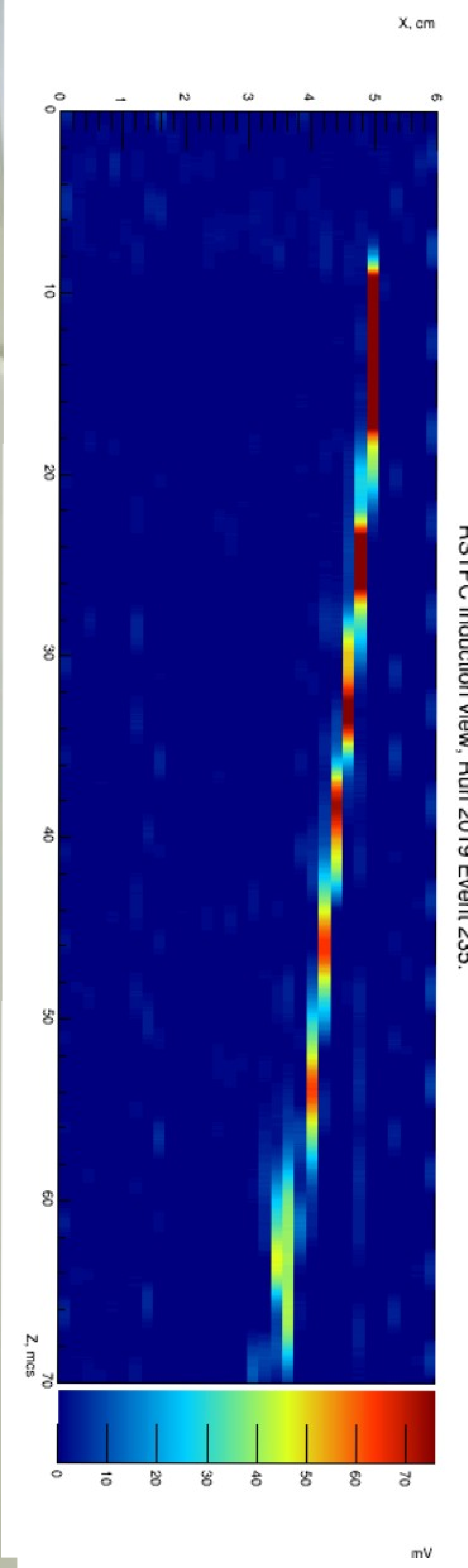
Resistive material can be used to provide a continuous potential distribution along the drift, minimal component an minimum points of failure.

In the case of a breakdown, a resistive plane would limit the rate of energy dissipation.

A suitable material must have a uniform resistance of O (10) GΩ sq^{-1} at −70 kV and 87 K.

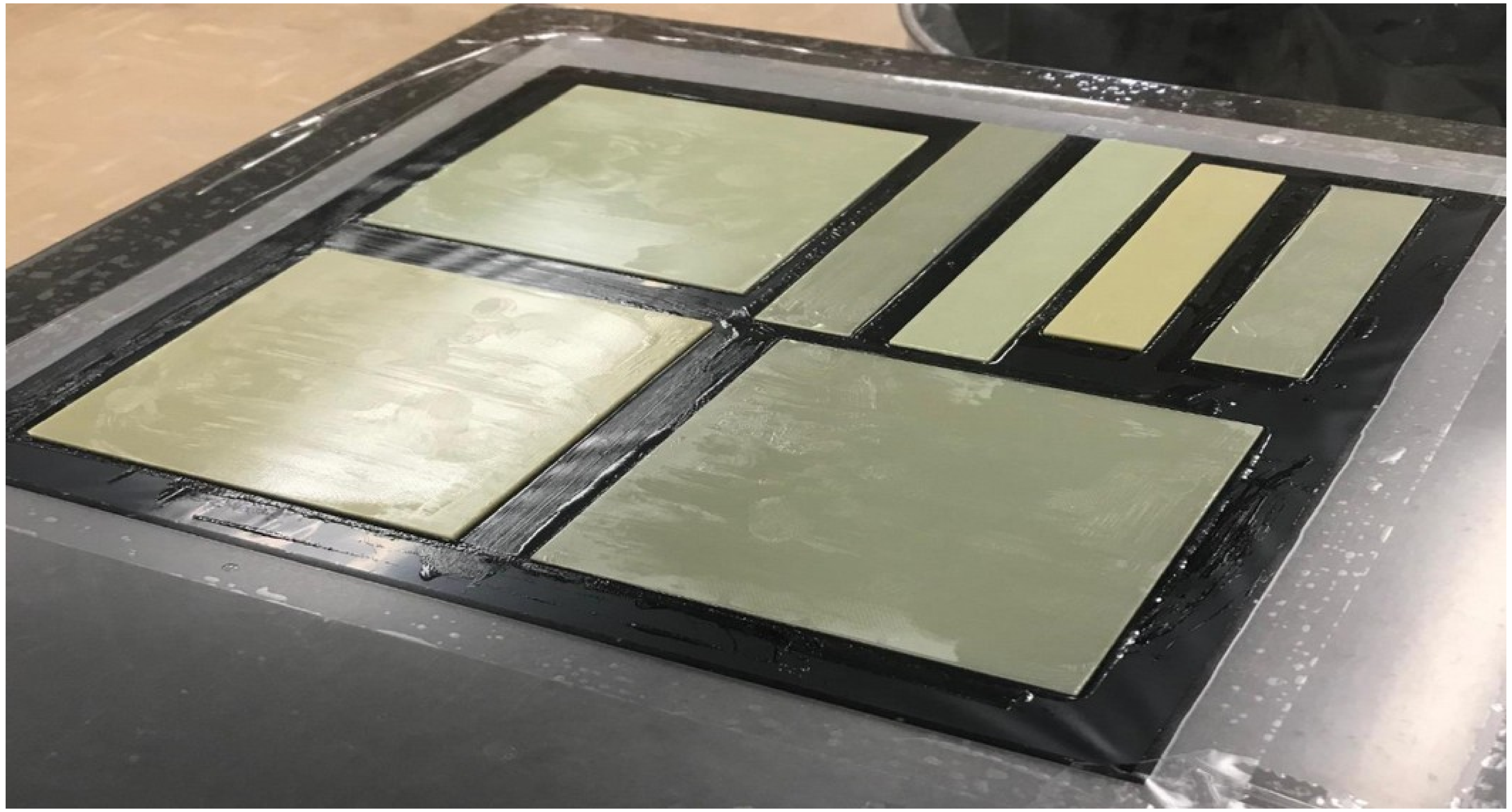
The field-shell can be produced as a laminate with a O (10) μm resistive layer on a G10 substrate.





Resistive Shell TPC Structure

The electro-magnetic radiation length (19.4 cm) of G10, and its hadronic interaction length (53.1 cm) are comparable to LAr, 14 cm and 83.7 cm, respectively.



Therefore G10 structures are not problematic for reconstruction.

A G10 substrate would also provide a strong dielectric, capable of 200 kV cm^{-1} at 1 cm thick, layer around the field-shell.

Dielectric shielding eliminates the need for clearance volumes between TPCs and the cryostat, and protects from breakdowns in a neighbouring TPC.

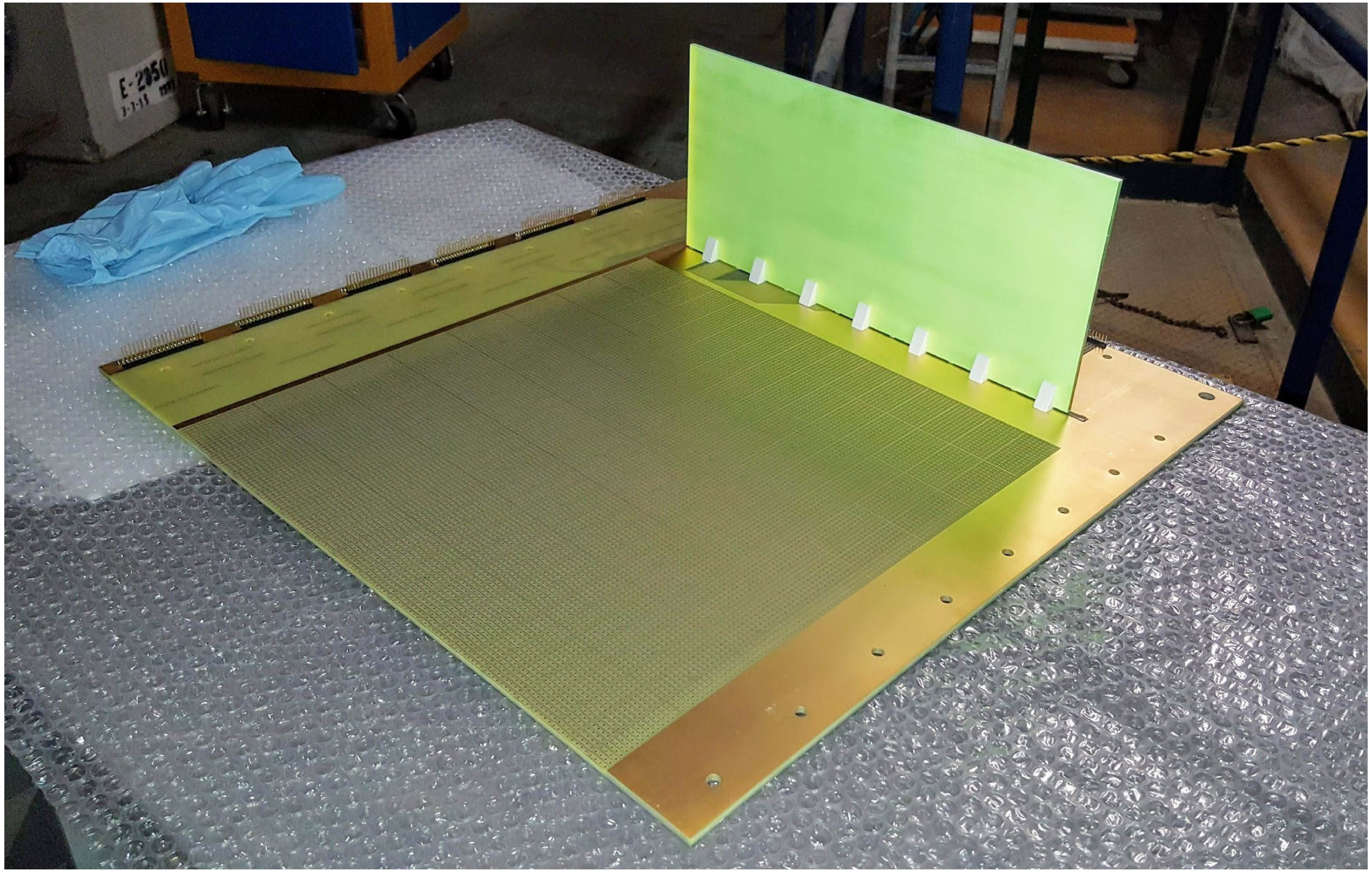
Contained Scintillation light

See Igor Kreslo's talk

Segmenting the detector contains scintillation within each TPC module.

The prompt component can be measured with improved accuracy, using a dielectric light readout, with O (1) ns timing resolution, deployed inside the TPC.

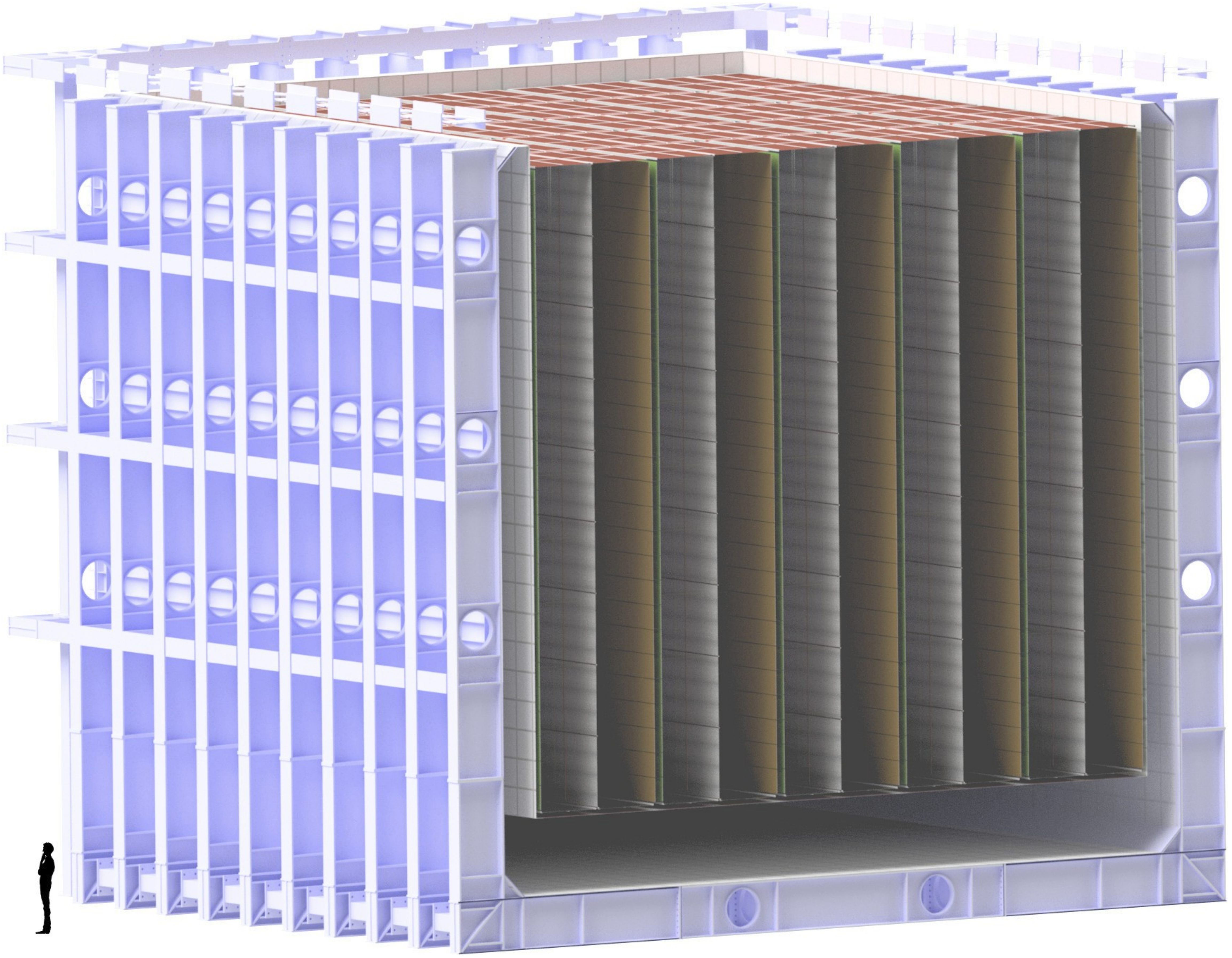
The optical path can be optimized to mitigate Rayleigh scattering.



Optimizing the design

The design presented here has obvious benefits to the DUNE physics program, but it is only optimized to reduce the risks associated with HV.

A detailed study is needed to optimize the design for cost, or physics requirements.

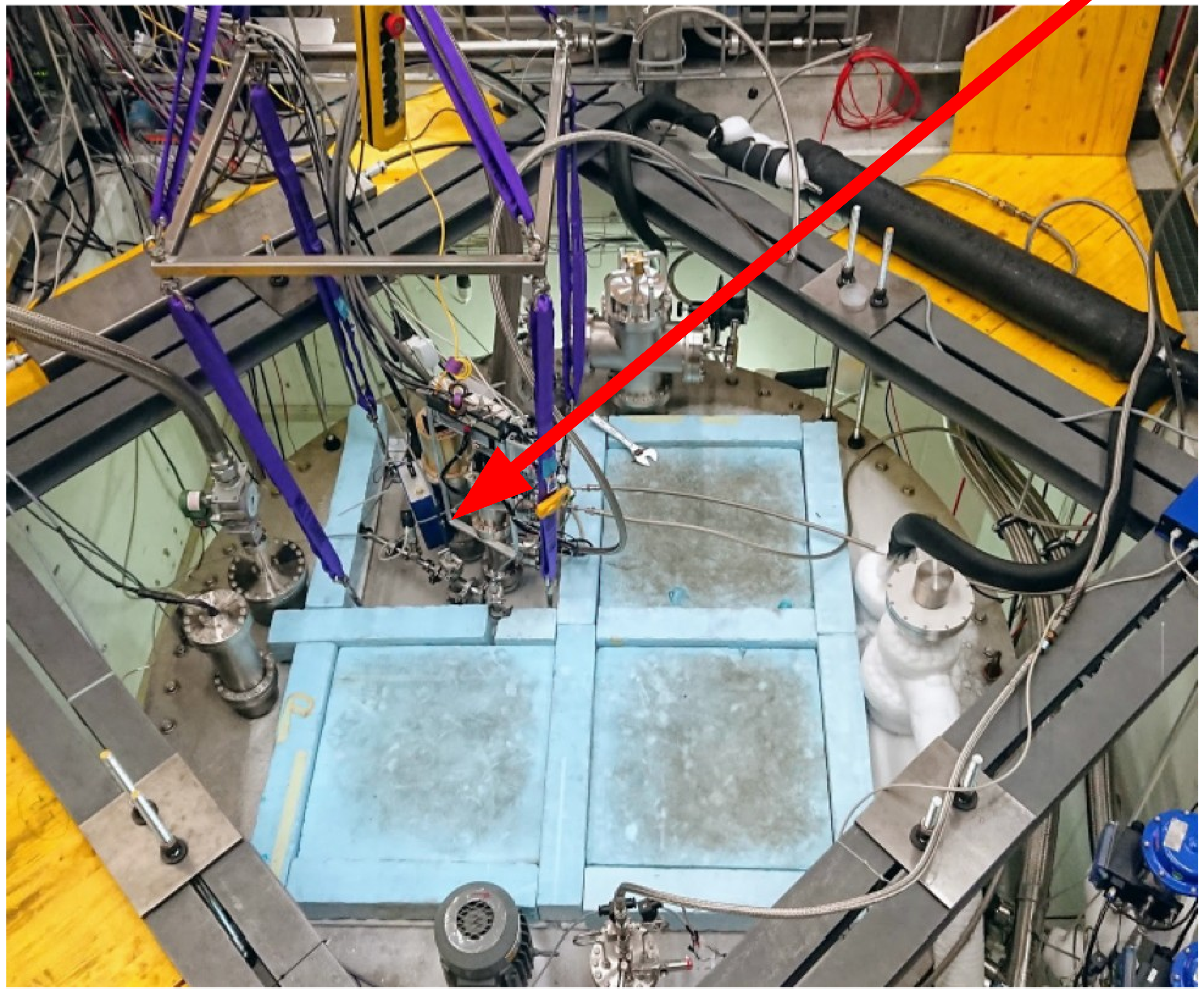


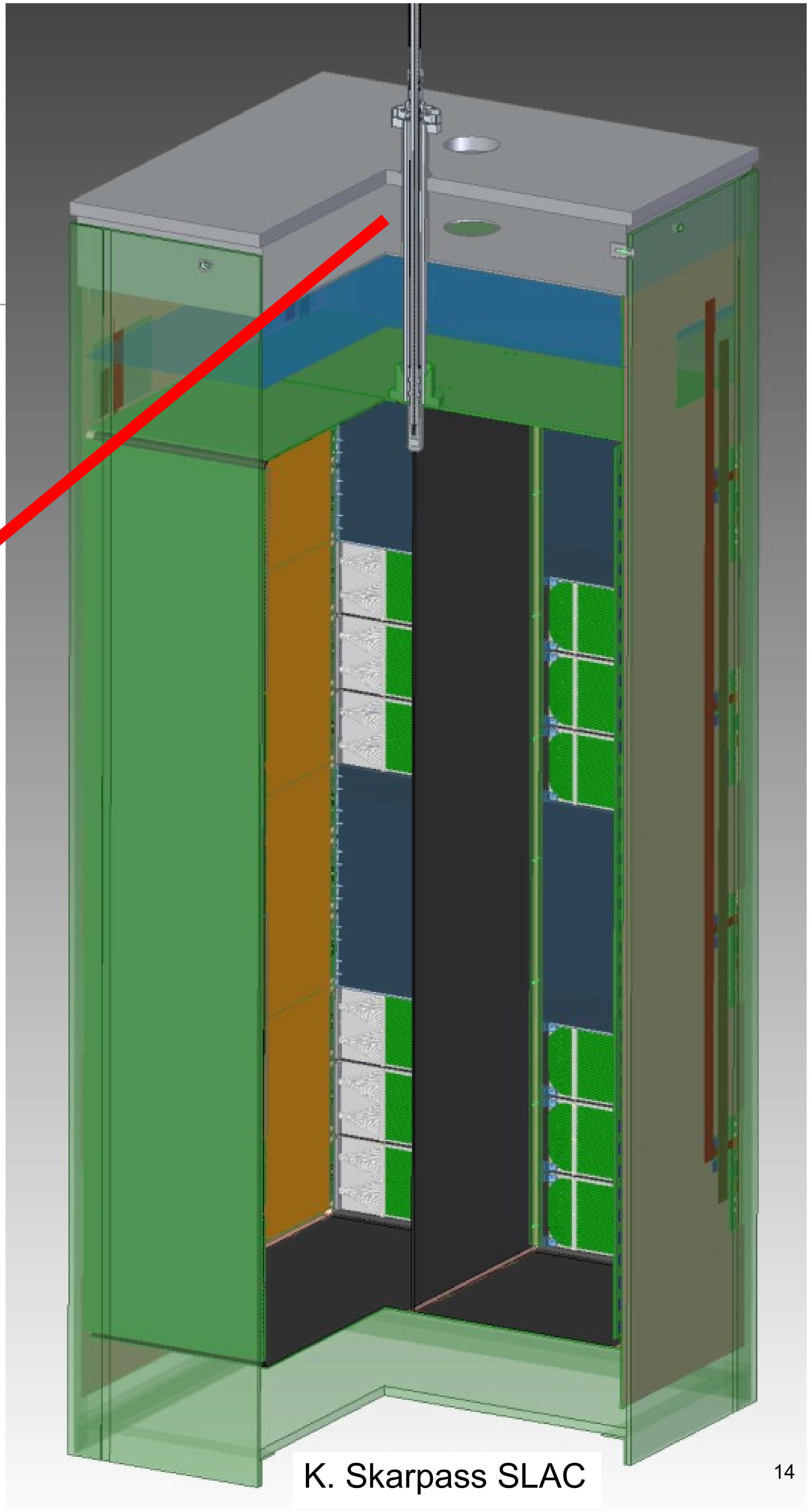
Prototyping a Modular LArTPC

As mentioned, this proposal has come from an extensive R&D program for the DUNE ND.

Although the physics requirements are different, many of the technologies are transferable to the FD

Therefore this FD design can makes use of the results of this R&D, which will be mature by the time of construction





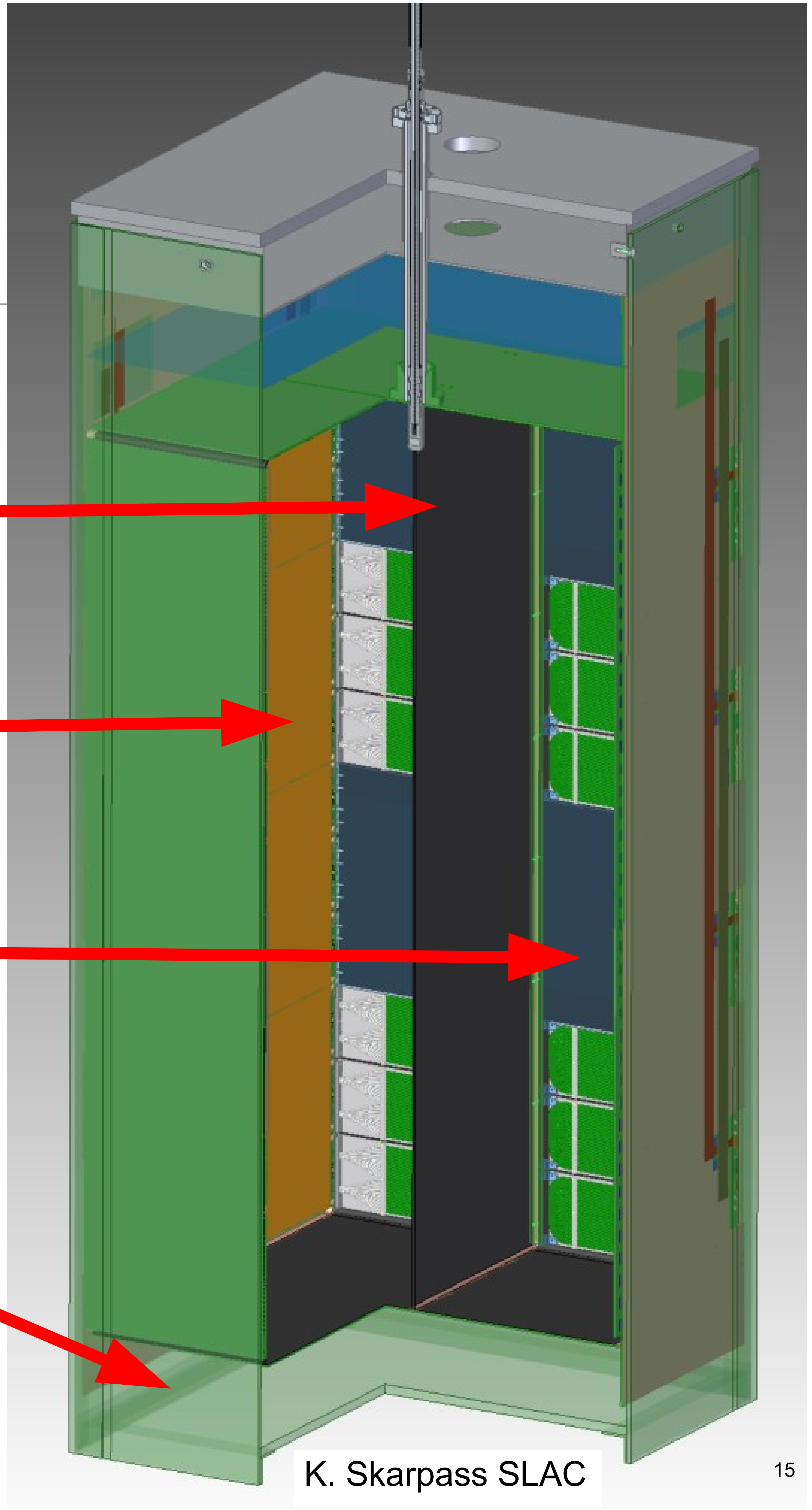
An ArgonCube Module

Central Cathode: splits the module into 2 TPCs

Pixelated anode plane

Dielectric light readout within TPCs

G10 structure: good dielectric shielding, and comparable radiation & hadronic interaction lengths to LAr



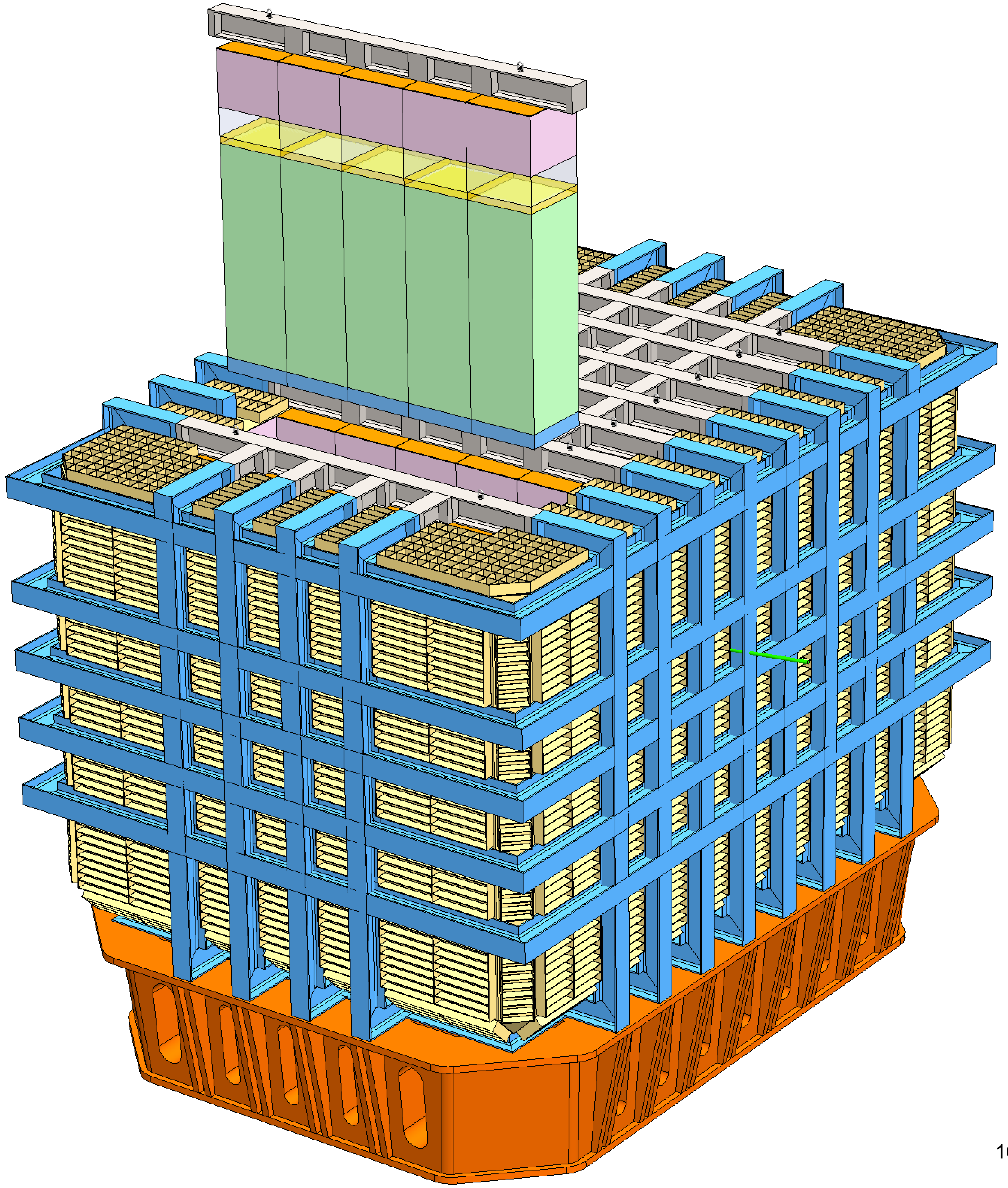
A Difference Near to Far

A core concept of the original ArgonCube proposal is module extraditable, to upgrade or repair without incurring long downtimes.

Given the lifespan of DUNE and the advancement of technology, it is desirable to be able to upgrade readout components.

Module extraction in the FD is not feasible.

But, anode extraction might be....



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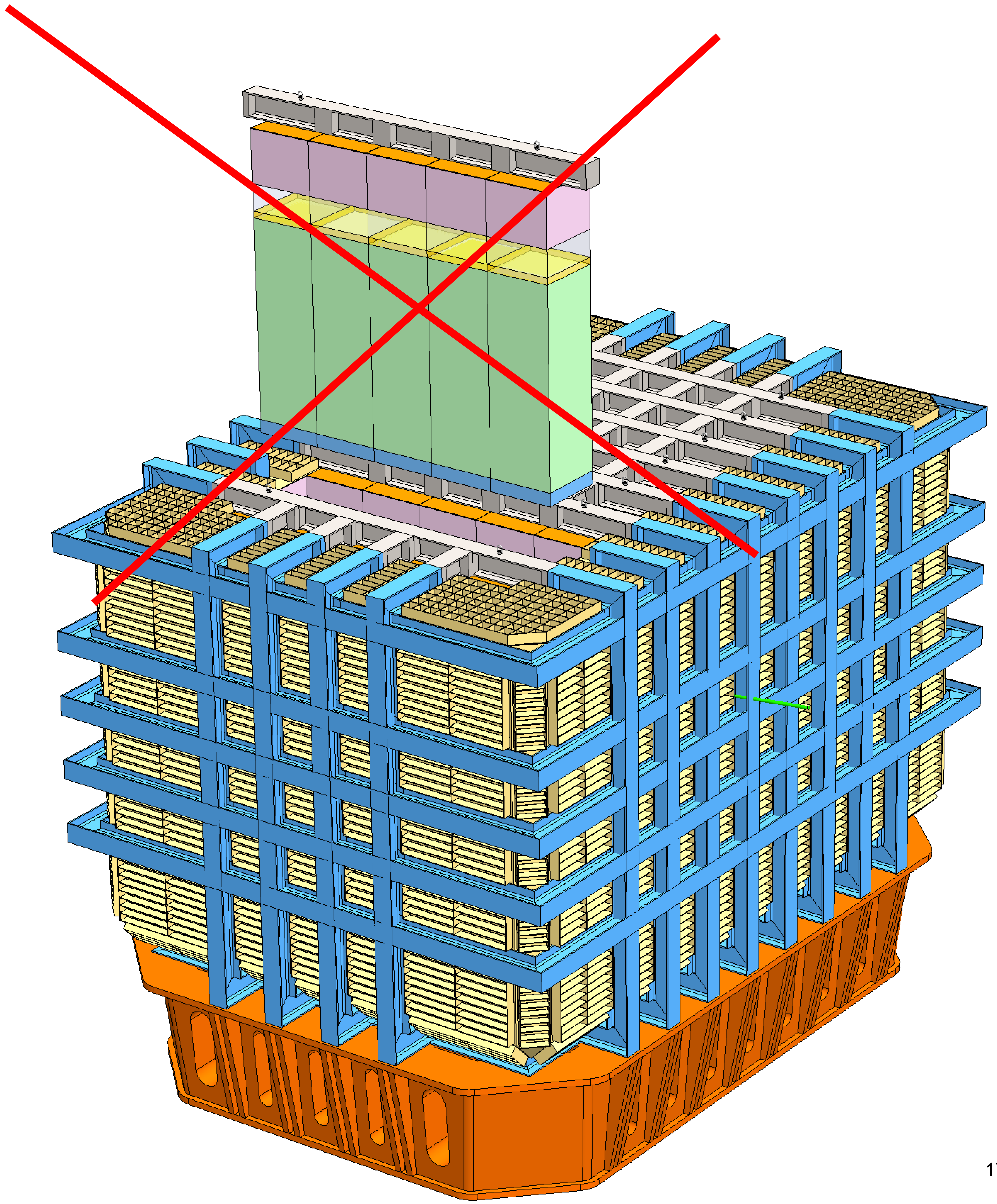
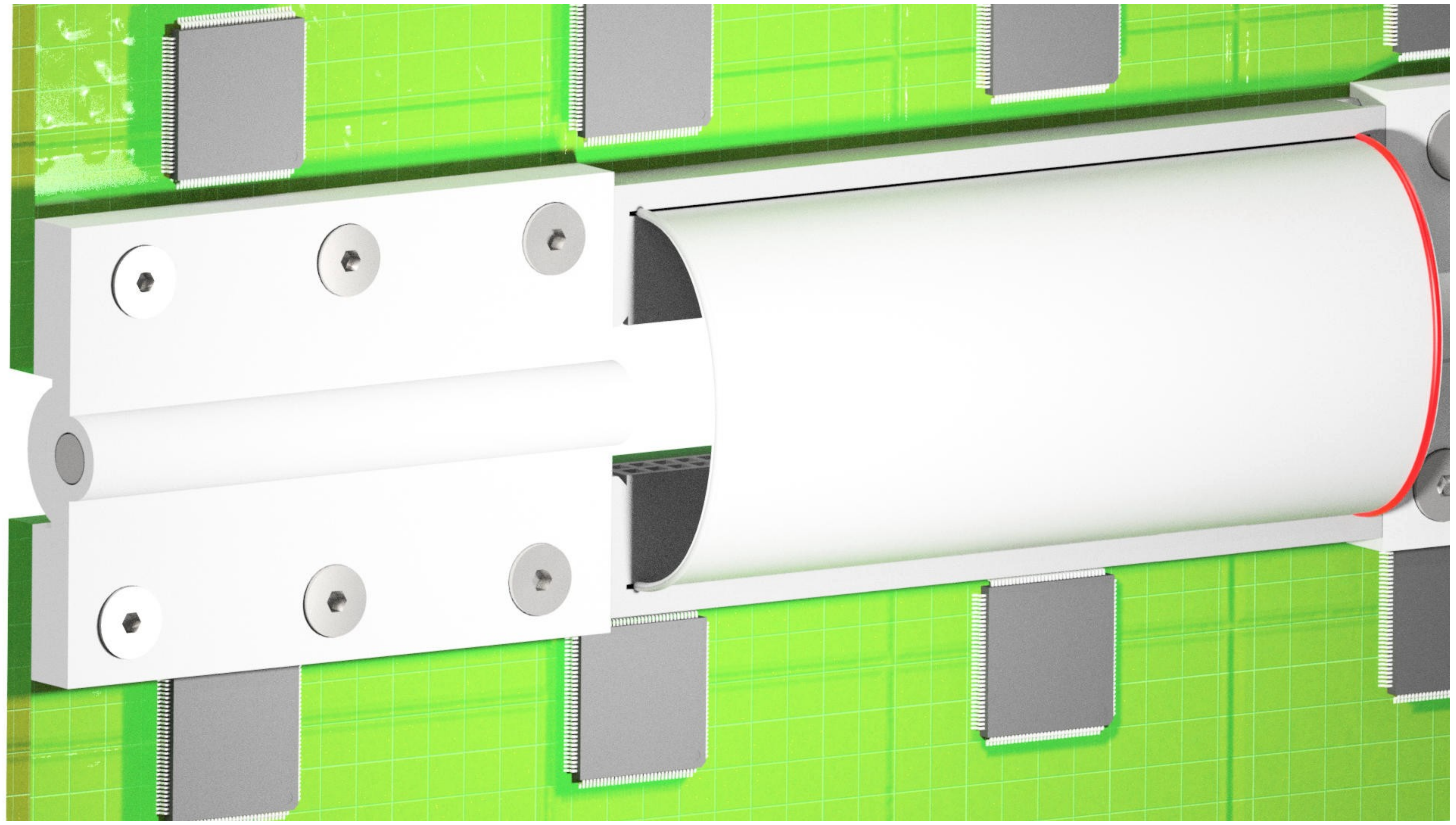
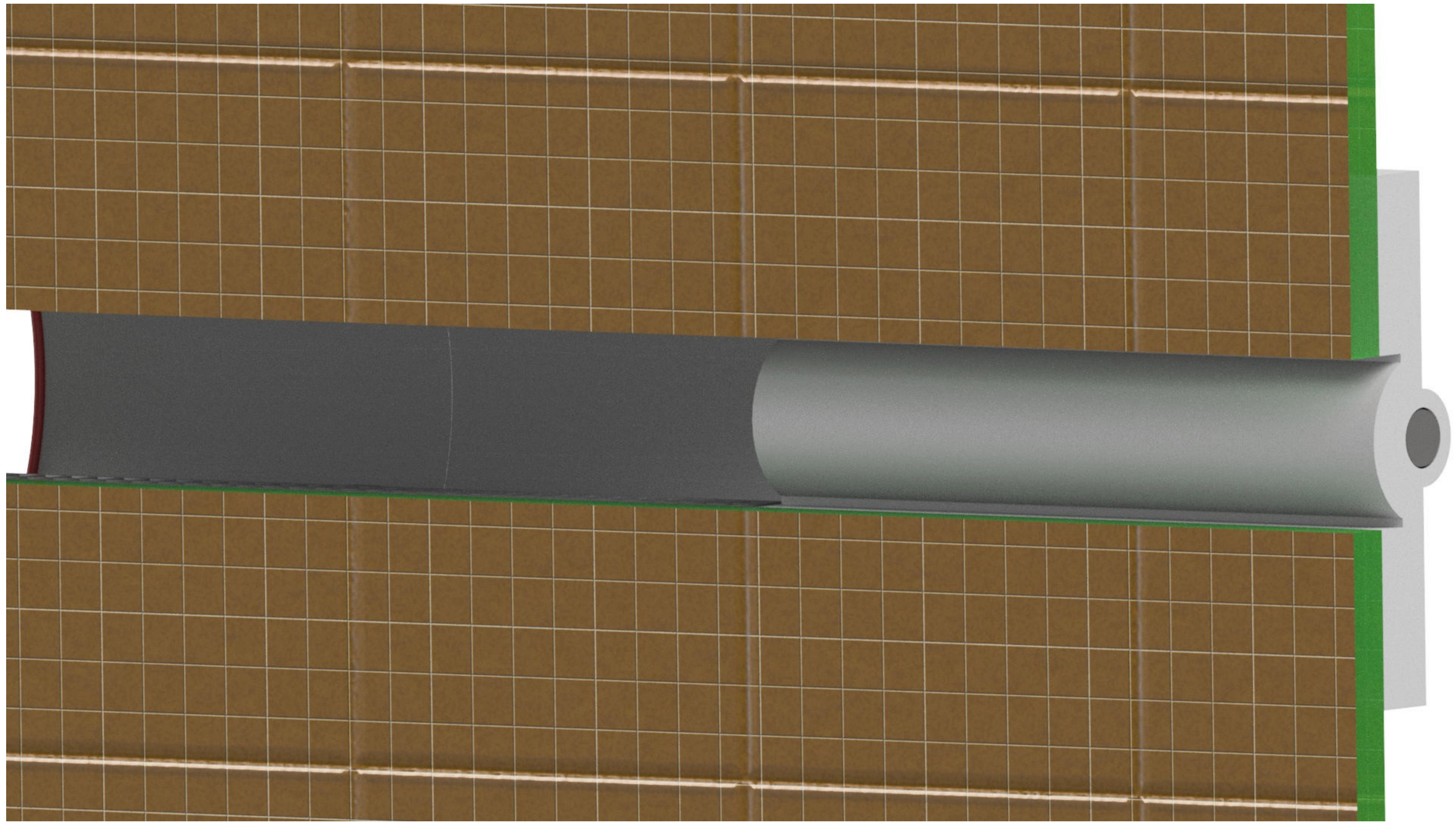


Extractable Pixel Anodes





We are investigating techniques to extract the anode plane vertically, through the cryostat top flange.

This would enable us to make use of ASIC development and continually optimize physics capabilities.

Conclusions

This design fulfils the requirements of the entire DUNE physics program.

LArPix improves the high angle performance and background rejection of the DUNE neutrino long-baseline oscillation programme.

Contained prompt scintillation light increases sensitivity to low energy events in DUNE’s physics programme (proton decay, solar- and supernova-neutrino).

The reduced HV requirements maintain detector performance, and drastically reduce energy which could be released in a breakdown.

Increased active mass is important for any stats-limited measurement.